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Carderock Division
Naval Surface Warfare Center

Bethesda, Maryland 20084-5000

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CARDIVNSWC-TR-82-93/28 September 1993

Machinery Research and Development Directorate
Research and Development Report

Automated Ship Auxiliary Systems Design Process -- Benefit Analysis Program

by
David J. Nordham

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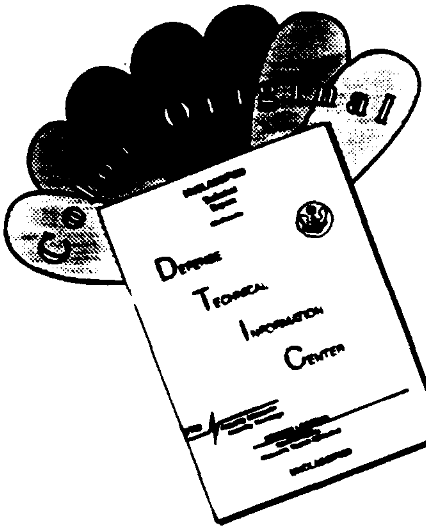

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Current design procedures often do not optimize the system characteristics (e.g., weight, volume, and cost) of auxiliary systems aboard U.S. Navy combatants. As a result, an automated design process was developed to examine the effect of design changes made to a surface ship auxiliary system on these characteristics. This process will allow comparison of different auxiliary system concepts for the selection of the best system configuration in a given combatant based on weight, volume, and cost impact on the ship. In addition, the design process will uniquely allow the examination of how design changes to an auxiliary system will impact different sized combatants. The automated design process is composed of two main programs -- a Ship Parametric Modeling Program in which the ship and auxiliary system model is developed in a parametric computer program for the NAVSEA CAD-2 system, and a Benefit Analysis Program in which the auxiliary system's characteristics are calculated for comparison to alternative components and system concepts. This report highlights the work done on the automated design process in FY 1993, specifically the work done on the Benefit Analysis Program. A description for use of the automated design process is also given. Test runs on several (Continued)

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variations to a parametric ship and piping model demonstrated that the design process will allow for comparisons of the system characteristics for the original and modified piping runs and aid in analyzing the impact of any modification made to the auxiliary system or the ship configuration. This new concept of auxiliary system definition and analysis will provide a significant evolution in system cost-effectiveness and ensure that all ship designs reflect the best available technology for the particular requirements.

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ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
CAD	Computer-Aided Design
FY	Fiscal Year
I/EMS	Intergraph Corporation's Engineering Modeling System
I/ROUTE	Intergraph Corporation's auxiliaries routing program
NAVSEA	Naval Sea Systems Command
NPS	Nominal Pipe Size
ONR	Office of Naval Research

ABSTRACT

Current design procedures often do not optimize the system characteristics (e.g., weight, volume, and cost) of auxiliary systems aboard U.S. Navy combatants. As a result, an automated design process was developed to examine the effect of design changes made to a surface ship auxiliary system on these characteristics. This process will allow comparison of different auxiliary system concepts for the selection of the best system configuration in a given combatant based on weight, volume, and cost impact on the ship. In addition, the design process will uniquely allow the examination of how design changes to an auxiliary system will impact different sized combatants. The automated design process is composed of two main programs -- a Ship Parametric Modeling Program in which the ship and auxiliary system model is developed in a parametric computer program for the NAVSEA CAD-2 system, and a Benefit Analysis Program in which the auxiliary system's characteristics are calculated for comparison to alternative components and system concepts. This report highlights the work done on the automated design process in FY 1993, specifically the work done on the Benefit Analysis Program. A description for use of the automated design process is also given. Test runs on several variations to a parametric ship and piping model demonstrated that the design process will allow for comparisons of the system characteristics for the original and modified piping runs and aid in analyzing the impact of any modification made to the auxiliary system or the ship configuration. This new concept of auxiliary system definition and analysis will provide a significant evolution in system cost-effectiveness and ensure that all ship designs reflect the best available technology for the particular requirements.

ADMINISTRATIVE INFORMATION

This report is submitted in partial fulfillment of Milestone 2, Task 3 of the Mechanical Power and Auxiliary Systems Project (RH21E42) of the Surface Ship Technology Block Program (SC1A/PE0602121N). The work described herein was sponsored by the Office of Naval Research (ONR 4524) and performed by the Carderock Division, Naval Surface Warfare Center, Annapolis Detachment, Code 824.

INTRODUCTION

Present auxiliary machinery programs develop specific pieces of machinery that are then assembled into an auxiliary system by a ship designer. This method does not allow the designer a chance to evaluate the impact of the system performance on the overall ship capability and cost, nor does it allow for the evaluation of alternative system designs. Previous work by Shiffler[1] examined an alternative approach to the design of auxiliary systems. This different approach, known as zonal architectures, employs the use of zones that can be isolated from the rest of the system without shutting down the entire system. A comparison between the current fire main system on board the DDG-51 and a hypothetical zonal fire main system design revealed that the zonal fire main design had potentially significant savings in the weight (17% savings), volume (8% savings), and cost (28% savings) over the current system.[1]

The results of the investigation into zonal architectures demonstrated the benefits of analyzing different design approaches for auxiliary system architectures. In order for the price-to-performance ratio of future ships to be optimized, a new design process needed to be developed which allows a fast analysis of the characteristics of current and alternative system designs. This design process would work best as an automated operation employing high-speed computers for analysis and evaluation of the proposed designs. An automated design process would allow a ship designer the capability of a quick comparison of several variations of a zonal auxiliary system within a given combatant or the capability of analyzing a new distribution system design in many different combatants. To this end, a 6.2 exploratory development task has been

ongoing at the Naval Surface Warfare Center, Carderock Division, to use state-of-the-art Computer-Aided Design (CAD) software and hardware to develop an automated ship auxiliary systems design process.

APPROACH

The automated design process is to be composed of two main programs. The first program is the Ship Parametric Modeling Program. This program utilizes parametric CAD software to model the ship and auxiliary systems. A CAD program is parametric when the dimensions and locations of certain parts of a model can be related, by mathematical equations, to a controlling parameter and these parts can then be automatically updated as the controlling parameter value is changed. By using the parametric features of the software, an auxiliary systems model can be created that is related mathematically to ship dimensions and layouts. When a new value is given to a controlling ship dimension, the ship model and associated auxiliary systems model change to reflect the new value. The output of the Ship Parametric Modeling Program is a list of the location and physical characteristics of the auxiliary systems components. Work on this program was done in fiscal year (FY) 1992 and reported by Nordham.[2]

The second program of the automated design process is the Benefit Analysis Program. This program accepts the components list from the Ship Parametric Modeling Program and calculates system characteristics (e.g., weight, volume, and cost). A report can then be generated for comparison to alternative designs for the auxiliary system. Work on this program was done in FY 1993.

This report describes the work done in FY 1993 on the automated ship auxiliary systems design process by the Naval Surface Warfare Center, Carderock Division -- specifically the work done on the Benefit Analysis Program.

BENEFIT ANALYSIS PROGRAM

The Benefit Analysis Program uses input obtained from the Ship Parametric Modeling Program. To demonstrate the automated auxiliary systems design process, parametric models representing the DDG-51 and zonal fire main system were created using the Ship Parametric Modeling Program as part of the FY 1992 effort.[2] The Ship Parametric Modeling Program utilizes Intergraph Corporation's Engineering Modeling System (I/EMS, Version 1.4.5.02)[3] CAD software with the support program for auxiliaries routing, I/ROUTE (Version 1.4.5.29).[4] The auxiliary system model was developed by separating the zonal fire main system into bulkhead-to-bulkhead compartment submodels. This was necessary to eliminate small mathematical differences between adjoining compartments and the resulting small, but unnoticeable, differences of adjoining piping runs. The output from the Ship Parametric Modeling Program was primarily two ASCII files for each bulkhead compartment that were created in I/ROUTE. The first of these files was created by Extracting Isometrics on the bulkhead section run, and had the file extension .h (i.e., file is *filename*.h). The second file was created by initiating the Stress Analysis Input program on the bulkhead section run, and had the extension .m (i.e., file is *filename*.m).

Small corrections had to be made to both of the Ship Parametric Modeling Program ASCII output files before the Benefit Analysis Program could accept them as input. The .h file contained several different sections which listed the x, y, and z locations of the pipe and piping components. The data required for input into the Benefit Analysis Program was contained in the section titled "Design file data sorted by topo." Therefore, all sections in the .h file before and after this topo section had to be deleted in the file. Also, included in the first part of the topo section was a list of the piping components and their locations. These components and locations were repeated later in this section with the listing of the pipe locations. To avoid double counting the components, the first part of the topo section had to be deleted. All deletions to the .h file were done using a word processing program that reads and writes DOS ASCII files.

A correction also had to be made to the .m file. The .m file contained information on the nominal pipe diameter of the pipe and piping components. This information initially included a double apostrophe mark as part of the nominal pipe diameter to indicate inches. These apostrophe marks were not used in the Benefit Analysis Program and, thus, were removed. All double apostrophe marks were replaced with a zero in the file. This replacement was done with a word processing program that reads and writes DOS ASCII files.

Once the .h and .m files were modified, the Benefit Analysis Program could be written. The first step in writing the Benefit Analysis Program was to determine the logical steps that were needed to be programmed to obtain the desired output. A flowchart showing these steps is presented in Appendix A. FORTRAN was chosen as

the programming language for the Benefit Analysis Program since the Ship Parametric Modeling Program's output is given in very organized columns and FORTRAN is a very receptive language to organized input. The steps were programmed and a listing of the Benefit Analysis Program is presented in Appendix B. Highlights of this program include:

- Prompts for the .h and .m filenames (include the extension .h or .m as part of the input), a bulkhead compartment identification, and density of the piping material (in lbm/in^3).

- Calculations for pipe length, weight (based on Schedule 40 pipe dimensions), volume (based on pipe outside diameter), and cost (obtained from Shiffler[1]).

- Calculations for component weight (based on Schedule 40 pipe dimensions), volume, unit cost (obtained from Shiffler[1]), and quantities.

- Calculations for the weight, volume, and cost of the piping system within a compartment.

- The pumps in the zonal fire main model of the Ship Parametric Modeling Program were attached from an external reference file and are not part of any piping data base in I/ROUTE. As a result, there was no way for the Extracting Isometrics or the Stress Analysis Input programs of I/ROUTE to register the pumps and their locations. Therefore, a piping component had to be placed at the pump's locations to allow the I/ROUTE programs to recognize the placement of a component. A piping cap was placed at the pump locations, since caps were not used elsewhere in this model. The .h file then included the cap locations as part of the Ship Parametric Modeling Program

output. Steps were included in the Benefit Analysis Program to convert the name "cap" into "pump" and the cap locations to the pump locations.

- The model representing the zonal fire main system used only 2, 4, and 6 in. nominal pipe size (NPS) pipe and fittings. Therefore, only these sizes were coded into the Benefit Analysis Program. Additional NPS sizes can be easily added as the situation warrants.

Once the Benefit Analysis Program was written, the procedure for the automated design process could be determined. This procedure is given in Appendix C. The next step was to test the automated design process by running various changes on the parametric model and calculating the system characteristics.

TESTING THE AUTOMATED DESIGN PROCESS

The automated design process was tested by making various modifications to the parametric DDG-51 and zonal fire main models. These modifications needed to encompass all the aspects that might be changed for an actual system analysis, i.e., any adjustments that could be made to the overall ship dimensions, to one bulkhead compartment, or to an individual piping run. Table 1 highlights the modifications made to the parametric models for each test run of the automated design process. Figure 1 demonstrates the original ship and auxiliary system model. The results of the Benefit Analysis Program for the auxiliary system characteristics of the piping system between bulkheads 2 and 3 are presented in Table 2. This output lists the nominal pipe size, length (for pipe), weight, volume, and cost of the individual piping run or component, in

addition to total lengths, quantities, weights, volumes, and costs for the entire piping system of that bulkhead section.

The second test run was a modification to the parametric model by changing the overall ship dimensions. The new ship and auxiliary system model is presented in Fig. 2 and the Benefit Analysis Program results for the piping run between bulkheads 2 and 3 of this test run are given in Table 3. Comparisons can be made using the output listed in Tables 2 and 3 to examine an auxiliary system design across different ship configurations.

The next test run was a modification to an individual compartment configuration, specifically changing the distance between bulkheads 2 and 3. Figure 3 shows the initial and modified bulkhead configurations, including the changes on the piping system in that compartment. The system characteristics for this test run are given in Table 4 for the piping system between bulkheads 2 and 3. A comparison between the output in Tables 2 and 4 would demonstrate the impact of individual compartment changes on the auxiliary systems in that compartment.

The fourth test run consisted of changing the layout of the piping system run between bulkheads 2 and 3. This change was accomplished by parametrically moving the pump location in the fire main model. Figure 4 shows the original and modified pump locations. Table 5 is the Benefit Analysis Program output of the system characteristics of the modified piping system. The effect of modifying the auxiliary system can been seen by comparing Tables 2 and 5.

The final test run consisted of adding pipe and components to the piping system between bulkheads 2 and 3. The original and new piping systems are displayed in Fig. 5. The system characteristics for this new piping system are presented in Table 6. Comparisons between Tables 2 and 6 can be done to examine the impact of adding or eliminating pipe and components to an auxiliary system.

CONCLUSIONS

Current Navy design procedures often do not optimize the system characteristics of shipboard auxiliary systems for minimum weight, volume, and cost. A new process of design and analysis was thus developed for rapid investigation of these characteristics to evaluate current and alternative system designs and provide guidelines for future research and development investment. This automated design process can be used to compare different auxiliary system concepts and aid in the selection of the best possible system configuration for a surface combatant. Test runs on several variations to the parametric models representing the DDG-51 and zonal fire main system demonstrated the capabilities of the design process. The Benefit Analysis Program gave results for the system characteristics of the original and modified piping runs and comparisons of these results illustrated the impact the various modifications made on the auxiliary system.

The automated design process allows a ship designer to determine the optimum auxiliary system architecture based on the Benefit Analysis Program results for system weight, volume, and cost within each bulkhead compartment. Other system

characteristics (e.g., component fabrication and installation costs, system reliability) may also be desired as part of an analysis, and equations for these could be added to the Benefit Analysis Program. The design selections found for a given system within one combatant configuration can then be easily analyzed across other ship configurations. This new concept of auxiliary system definition and analysis will provide a significant evolution in system cost-effectiveness and ensure that all ship designs reflect the best available technology for the particular requirements.

Table 1. Modifications to parametric models

Run number	Description of model
1	Original ship dimensions (length=505 ft., width=66 ft., height=36 ft.)
2	Changed ship dimensions (length=400 ft., width=100 ft., height=50 ft.)
3	Original ship dimensions, changed distance between bulkheads 2 and 3 from 36 ft. to 20 ft.
4	Original ship dimensions, moved pump in compartment between bulkheads 2 and 3 from fourth deck to second deck
5	Original ship dimensions, added piping and components to system running between bulkheads 2 and 3

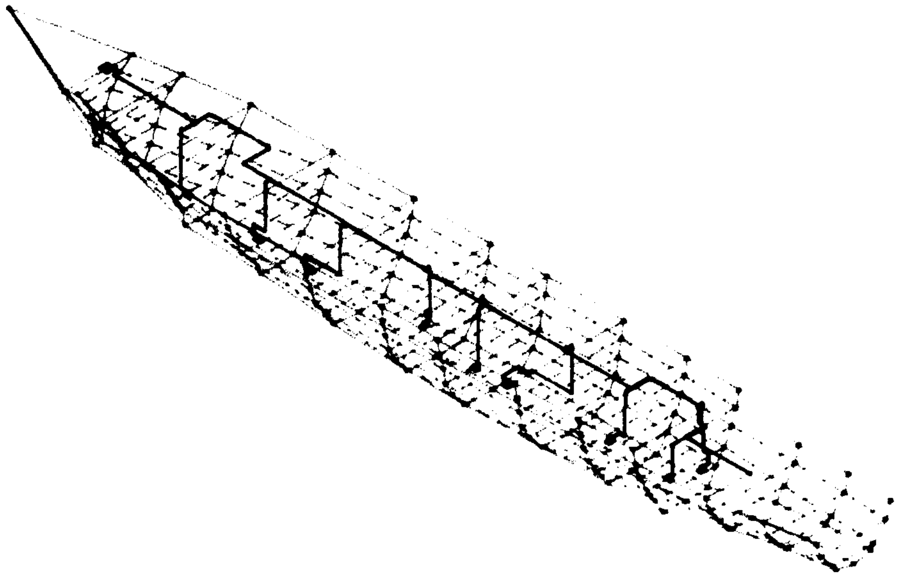


Fig. 1. Ship and piping model with original dimensions of 505 ft. length, 66 ft. width, and 36 ft. height.

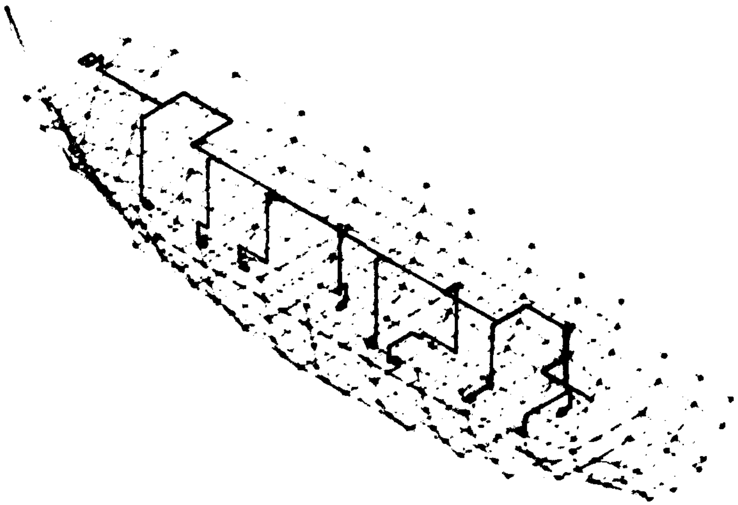


Fig. 2. Ship and piping model with new dimensions of 400 ft. length, 100 ft. width, and 50 ft. height.

Table 2. Benefit Analysis Program results for ship model with original dimensions (run number 1).

COMP	OCC	NPS	LENGTH	WEIGHT	VOLUME	COST
PIPE	8.	6.00	6.38	16.90	219.93	$ 242.76
PIPE	23.	6.00	69.37	183.72	2391.29	$ 2639.53
PIPE	16.	6.00	87.37	231.40	3011.78	$ 3324.43
PIPE	21.	6.00	16.00	42.38	551.55	$ 608.80
PIPE	18.	4.00	38.04	52.09	605.00	$ 688.52
PIPE	4.	4.00	3.00	4.11	47.71	$ 54.30
PIPE	6.	4.00	358.00	490.20	5693.74	$ 6479.80
PIPE	7.	4.00	33.00	45.19	524.84	$ 597.30
PIPE	13.	6.00	312.88	828.65	10785.47	$ 11905.08
GLO	11.	6.00	---	219.80	1425.50	$ 3530.00
90E	15.	6.00	---	24.50	620.49	$ 1491.73
TEE	12.	6.00	---	34.00	467.54	$ 3088.29
CRED	14.	6.00	---	8.25	138.52	$ 1048.22
CRED	20.	6.00	---	8.25	138.52	$ 1048.22
GLO	10.	4.00	---	101.50	667.98	$ 3530.00
90E	2.	4.00	---	9.00	190.85	$ 962.76
90E	3.	4.00	---	9.00	190.85	$ 962.76
90E	5.	4.00	---	9.00	190.85	$ 962.76
PUMP	1.	4.00	---	2695.00	54086.40	$ 40167.00

TOTALS FOR COMPARTMENT BETWEEN BULKHEADS 2 AND 3
WITH MATERIAL DENSITY OF .283 LB/IN^3

TOTAL LENGTH OF 4 IN. PIPE IS 432.04 IN. WITH A TOTAL COST OF $ 7819.92
TOTAL LENGTH OF 6 IN. PIPE IS 492.00 IN. WITH A TOTAL COST OF $ 18720.60

TOTAL NO. OF 4 IN. ELBOWS 3 WITH A TOTAL COST OF $ 2888.28
TOTAL NO. OF 6 IN. ELBOWS 1 WITH A TOTAL COST OF $ 1491.73
TOTAL NO. OF 6 IN. TEES 1 WITH A TOTAL COST OF $ 3088.29
TOTAL NO. OF 6X4 REDUCERS 2 WITH A TOTAL COST OF $ 2096.44
TOTAL NO. OF 4 IN. VALVES 1 WITH A TOTAL COST OF $ 3530.00
TOTAL NO. OF 6 IN. VALVES 1 WITH A TOTAL COST OF $ 3530.00
TOTAL NO. OF PUMPS 1 WITH A TOTAL COST OF $ 40167.00

TOTAL WEIGHT OF THIS SECTION IS 5012.92 LBS.
TOTAL VOLUME OF THIS SECTION IS 81948.81 IN^3
TOTAL COST OF THIS SECTION IS $ 83332.27

Table 3. Benefit Analysis Program results for ship model with modified dimensions (run number 2).

COMP	OCC	NPS	LENGTH	WEIGHT	VOLUME	COST
PIPE	8.	6.00	6.38	16.90	219.93	$ 242.76
PIPE	23.	6.00	46.83	124.03	1614.31	$ 1781.88
PIPE	16.	6.00	139.92	370.57	4823.26	$ 5323.96
PIPE	21.	6.00	16.00	42.38	551.55	$ 608.80
PIPE	18.	4.00	83.85	114.81	1333.58	$ 1517.69
PIPE	4.	4.00	3.00	4.11	47.71	$ 54.30
PIPE	6.	4.00	501.89	687.23	7982.21	$ 9084.21
PIPE	7.	4.00	27.99	38.33	445.16	$ 506.62
PIPE	13.	6.00	245.24	649.51	8453.81	$ 9331.38
GLO	11.	6.00	---	219.80	1425.50	$ 3530.00
90E	15.	6.00	---	24.50	620.49	$ 1491.73
TEE	12.	6.00	---	34.00	467.54	$ 3088.29
CRED	14.	6.00	---	8.25	138.52	$ 1048.22
CRED	20.	6.00	---	8.25	138.52	$ 1048.22
GLO	10.	4.00	---	101.50	667.98	$ 3530.00
90E	2.	4.00	---	9.00	190.85	$ 962.76
90E	3.	4.00	---	9.00	190.85	$ 962.76
90E	5.	4.00	---	9.00	190.85	$ 962.76
PUMP	1.	4.00	---	2695.00	54086.40	$ 40167.00

TOTALS FOR COMPARTMENT BETWEEN BULKHEADS 2 AND 3
WITH MATERIAL DENSITY OF .283 LB/IN^3

TOTAL LENGTH OF 4 IN. PIPE IS 616.73 IN. WITH A TOTAL COST OF $ 11162.81
TOTAL LENGTH OF 6 IN. PIPE IS 454.37 IN. WITH A TOTAL COST OF $ 17288.78

TOTAL NO. OF 4 IN. ELBOWS 3 WITH A TOTAL COST OF $ 2888.28
TOTAL NO. OF 6 IN. ELBOWS 1 WITH A TOTAL COST OF $ 1491.73
TOTAL NO. OF 6 IN. TEES 1 WITH A TOTAL COST OF $ 3088.29
TOTAL NO. OF 6X4 REDUCERS 2 WITH A TOTAL COST OF $ 2096.44
TOTAL NO. OF 4 IN. VALVES 1 WITH A TOTAL COST OF $ 3530.00
TOTAL NO. OF 6 IN. VALVES 1 WITH A TOTAL COST OF $ 3530.00
TOTAL NO. OF PUMPS 1 WITH A TOTAL COST OF $ 40167.00

TOTAL WEIGHT OF THIS SECTION IS 5166.15 LBS.
TOTAL VOLUME OF THIS SECTION IS 83589.02 IN^3
TOTAL COST OF THIS SECTION IS $ 85243.34

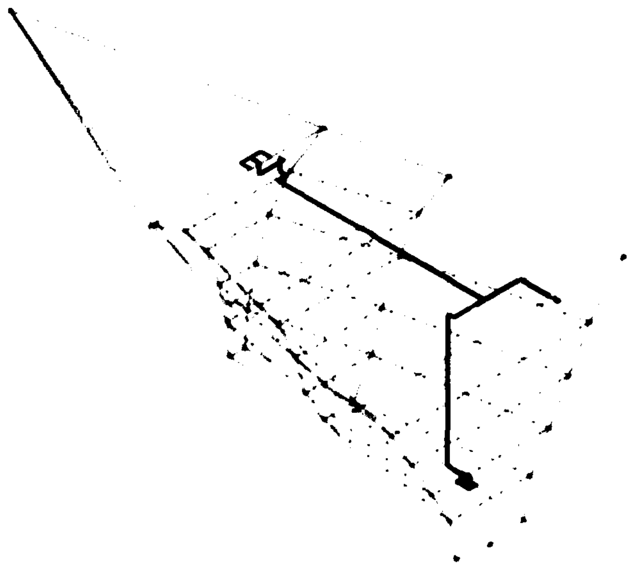


Fig. 3a. Distance between bulkheads 2 and 3 of 36 ft.

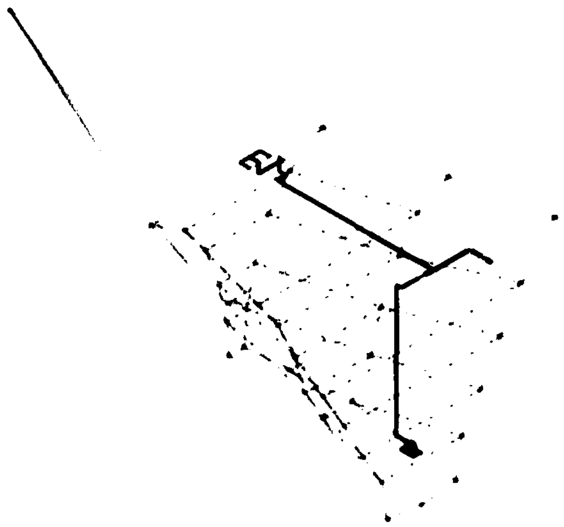


Fig. 3b. Distance between bulkheads 2 and 3 of 20 ft.

Table 4. Benefit Analysis Program results for ship model with modified distance between bulkheads 2 and 3 (run number 3).

COMP	OCC	NPS	LENGTH	WEIGHT	VOLUME		COST
PIPE	8.	6.00	6.38	16.90	219.93	$	242.76
PIPE	23.	6.00	21.37	56.60	736.66	$	813.13
PIPE	16.	6.00	87.37	231.40	3011.78	$	3324.43
PIPE	21.	6.00	16.00	42.38	551.55	$	608.80
PIPE	18.	4.00	38.04	52.09	605.00	$	688.52
PIPE	4.	4.00	3.00	4.11	47.71	$	54.30
PIPE	6.	4.00	358.00	490.20	5693.74	$	6479.80
PIPE	7.	4.00	22.33	30.58	355.14	$	404.17
PIPE	13.	6.00	168.88	447.27	5821.56	$	6425.88
GLO	11.	6.00	---	219.80	1425.50	$	3530.00
90E	15.	6.00	---	24.50	620.49	$	1491.73
TEE	12.	6.00	---	34.00	467.54	$	3088.29
CRED	14.	6.00	---	8.25	138.52	$	1048.22
CRED	20.	6.00	---	8.25	138.52	$	1048.22
GLO	10.	4.00	---	101.50	667.98	$	3530.00
90E	2.	4.00	---	9.00	190.85	$	962.76
90E	3.	4.00	---	9.00	190.85	$	962.76
90E	5.	4.00	---	9.00	190.85	$	962.76
PUMP	1.	4.00	---	2695.00	54086.40	$	40167.00

TOTALS FOR COMPARTMENT BETWEEN BULKHEADS 2 AND 3
WITH MATERIAL DENSITY OF .283 LB/IN^3

TOTAL LENGTH OF 4 IN. PIPE IS 421.37 IN. WITH A TOTAL COST OF $ 7626.80
TOTAL LENGTH OF 6 IN. PIPE IS 300.00 IN. WITH A TOTAL COST OF $ 11415.00

TOTAL NO. OF 4 IN. ELBOWS 3 WITH A TOTAL COST OF $ 2888.28
TOTAL NO. OF 6 IN. ELBOWS 1 WITH A TOTAL COST OF $ 1491.73
TOTAL NO. OF 6 IN. TEES 1 WITH A TOTAL COST OF $ 3088.29
TOTAL NO. OF 6X4 REDUCERS 2 WITH A TOTAL COST OF $ 2096.44
TOTAL NO. OF 4 IN. VALVES 1 WITH A TOTAL COST OF $ 3530.00
TOTAL NO. OF 6 IN. VALVES 1 WITH A TOTAL COST OF $ 3530.00
TOTAL NO. OF PUMPS 1 WITH A TOTAL COST OF $ 40167.00

TOTAL WEIGHT OF THIS SECTION IS 4489.81 LBS.
TOTAL VOLUME OF THIS SECTION IS 75160.56 IN^3
TOTAL COST OF THIS SECTION IS $ 75833.55

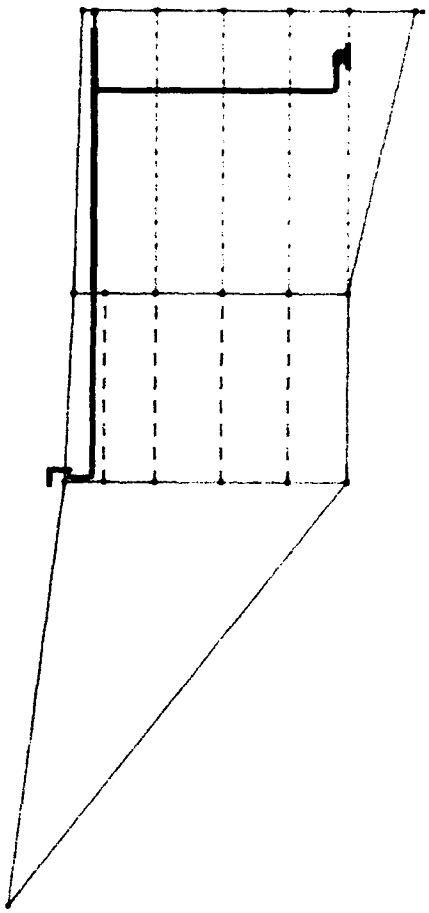


Fig. 4a. Pump located on fourth deck.

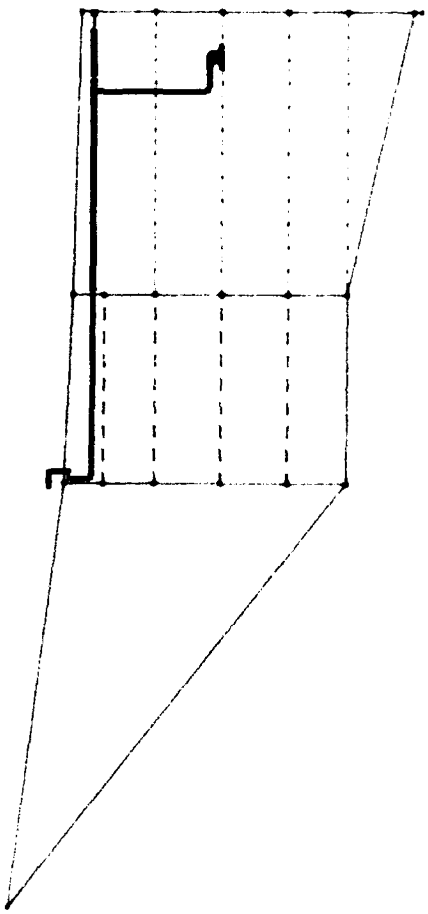


Fig. 4b. Pump located on second deck.

Table 5. Benefit Analysis Program results for ship model with modified pump location (run number 4).

COMP	OCC	NPS	LENGTH	WEIGHT	VOLUME	COST
PIPE	8.	6.00	6.38	16.90	219.93	$ 242.76
PIPE	23.	6.00	69.37	183.72	2391.29	$ 2639.53
PIPE	16.	6.00	87.37	231.40	3011.78	$ 3324.43
PIPE	21.	6.00	16.00	42.38	551.55	$ 608.80
PIPE	18.	4.00	38.04	52.09	605.00	$ 688.52
PIPE	4.	4.00	3.00	4.11	47.71	$ 54.30
PIPE	6.	4.00	166.00	227.30	2640.11	$ 3004.60
PIPE	7.	4.00	33.00	45.19	524.84	$ 597.30
PIPE	13.	6.00	312.88	828.65	10785.47	$ 11905.08
GLO	11.	6.00	---	219.80	1425.50	$ 3530.00
90E	15.	6.00	---	24.50	620.49	$ 1491.73
TEE	12.	6.00	---	34.00	467.54	$ 3088.29
CRED	14.	6.00	---	8.25	138.52	$ 1048.22
CRED	20.	6.00	---	8.25	138.52	$ 1048.22
GLO	10.	4.00	---	101.50	667.98	$ 3530.00
90E	2.	4.00	---	9.00	190.85	$ 962.76
90E	3.	4.00	---	9.00	190.85	$ 962.76
90E	5.	4.00	---	9.00	190.85	$ 962.76
PUMP	1.	4.00	---	2695.00	54086.40	$ 40167.00

TOTALS FOR COMPARTMENT BETWEEN BULKHEADS 2 AND 3
WITH MATERIAL DENSITY OF .283 LB/IN^3

TOTAL LENGTH OF 4 IN. PIPE IS 240.04 IN. WITH A TOTAL COST OF $ 4344.72
TOTAL LENGTH OF 6 IN. PIPE IS 492.00 IN. WITH A TOTAL COST OF $ 18720.60

TOTAL NO. OF 4 IN. ELBOWS 3 WITH A TOTAL COST OF $ 2888.28
TOTAL NO. OF 6 IN. ELBOWS 1 WITH A TOTAL COST OF $ 1491.73
TOTAL NO. OF 6 IN. TEES 1 WITH A TOTAL COST OF $ 3088.29
TOTAL NO. OF 6X4 REDUCERS 2 WITH A TOTAL COST OF $ 2096.44
TOTAL NO. OF 4 IN. VALVES 1 WITH A TOTAL COST OF $ 3530.00
TOTAL NO. OF 6 IN. VALVES 1 WITH A TOTAL COST OF $ 3530.00
TOTAL NO. OF PUMPS 1 WITH A TOTAL COST OF $ 40167.00

TOTAL WEIGHT OF THIS SECTION IS 4750.02 LBS.
TOTAL VOLUME OF THIS SECTION IS 78895.19 IN^3
TOTAL COST OF THIS SECTION IS $ 79857.07

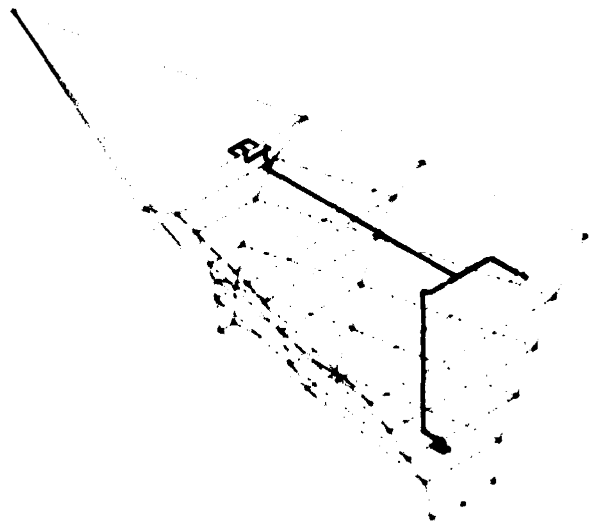


Fig. 5a. Original piping layout.

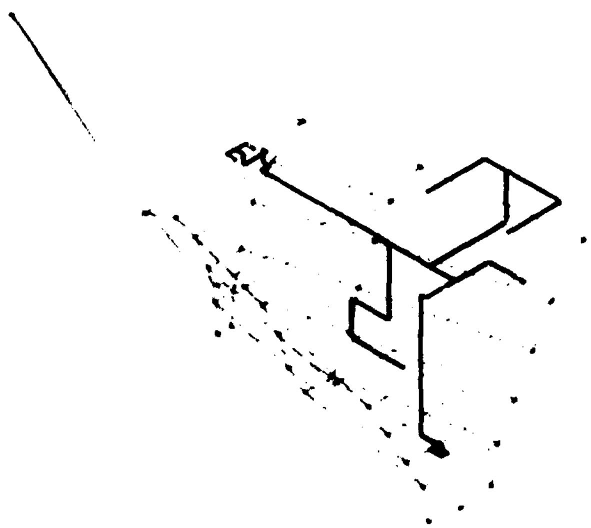


Fig. 5b. Pipe and components added to piping layout.

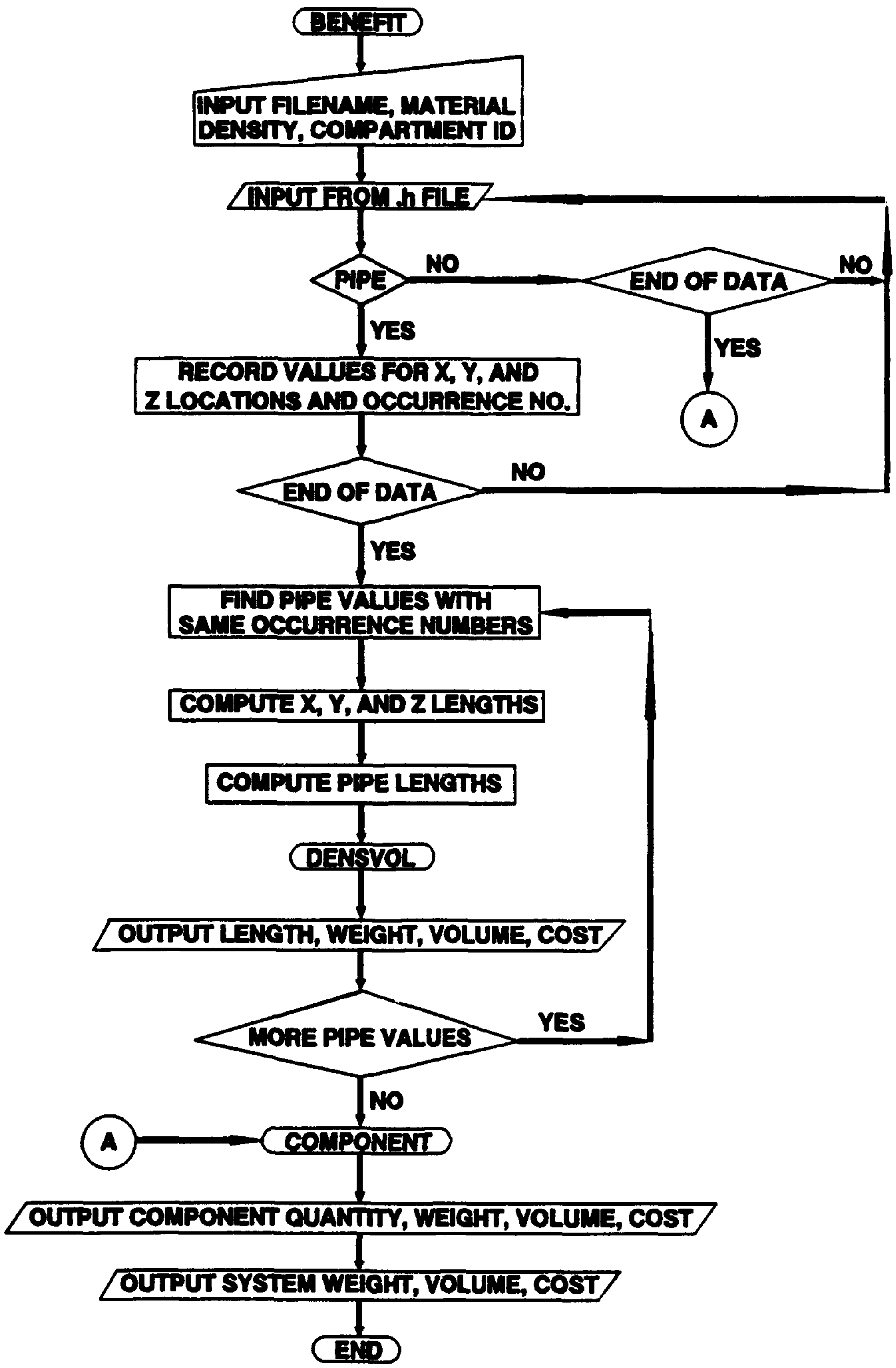
Table 6. Benefit Analysis Program results for ship model with added piping and components (run number 5).

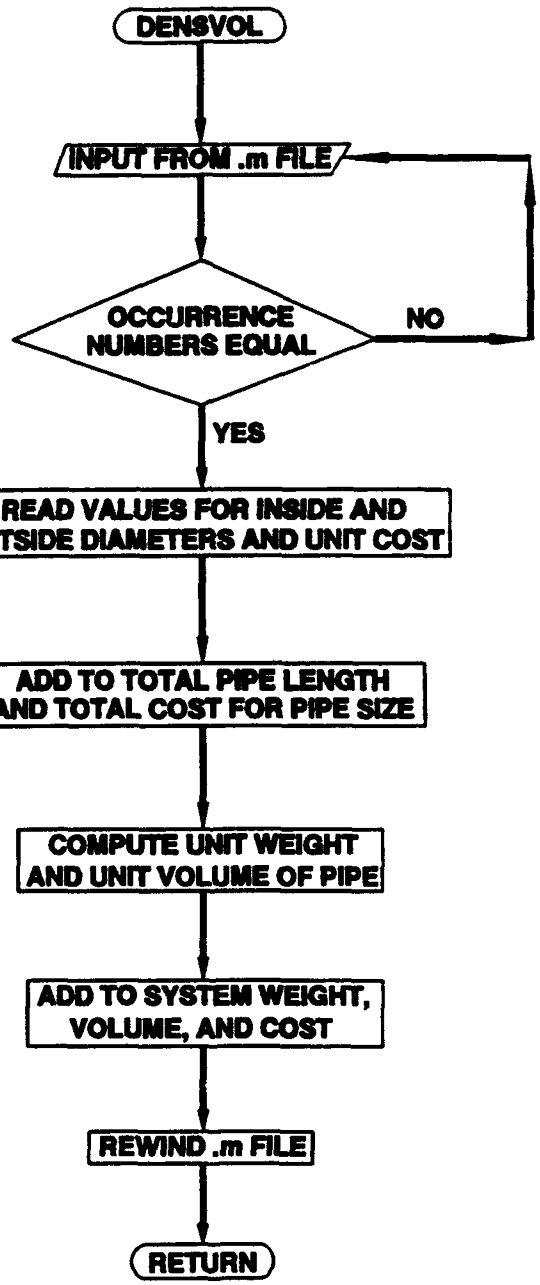
COMP	OCC	NPS	LENGTH	WEIGHT	VOLUME		COST
PIPE	11.	6.00	6.38	16.90	219.93	$	242.76
PIPE	32.	6.00	69.37	183.72	2391.29	$	2639.53
PIPE	22.	6.00	87.37	231.40	3011.78	$	3324.43
PIPE	30.	6.00	16.00	42.38	551.55	$	608.80
PIPE	25.	4.00	38.04	52.09	605.00	$	688.52
PIPE	4.	4.00	3.00	4.11	47.71	$	54.30
PIPE	6.	4.00	358.00	490.20	5693.74	$	6479.80
PIPE	7.	4.00	33.00	45.19	524.84	$	597.30
PIPE	19.	6.00	66.76	176.81	2301.32	$	2540.22
PIPE	45.	6.00	110.74	293.29	3817.38	$	4213.66
PIPE	10.	6.00	112.88	298.96	3891.15	$	4295.08
PIPE	20.	6.00	189.94	503.05	6547.53	$	7227.22
PIPE	40.	6.00	98.17	260.00	3384.08	$	3735.37
PIPE	42.	6.00	86.14	228.14	2969.38	$	3277.63
PIPE	43.	6.00	149.38	395.63	5149.36	$	5683.91
PIPE	13.	6.00	222.55	589.41	7671.65	$	8468.03
PIPE	17.	6.00	119.55	316.62	4121.08	$	4548.88
PIPE	33.	4.00	158.52	217.06	2521.15	$	2869.21
PIPE	27.	4.00	149.36	204.51	2375.47	$	2703.42
PIPE	37.	4.00	47.16	64.58	750.05	$	853.60
PIPE	38.	4.00	168.92	231.30	2686.55	$	3057.45
GLO	16.	6.00	---	219.80	1425.50	$	3530.00
90E	21.	6.00	---	24.50	620.49	$	1491.73
TEE	18.	6.00	---	34.00	467.54	$	3088.29
TEE	44.	6.00	---	34.00	467.54	$	3088.29
90E	12.	6.00	---	24.50	620.49	$	1491.73
TEE	24.	6.00	---	34.00	467.54	$	3088.29
CRED	46.	6.00	---	8.25	138.52	$	1048.22
90E	26.	4.00	---	9.00	190.85	$	962.76
CRED	35.	6.00	---	8.25	138.52	$	1048.22
90E	36.	4.00	---	9.00	190.85	$	962.76
TEE	8.	6.00	---	34.00	467.54	$	3088.29
90E	34.	6.00	---	24.50	620.49	$	1491.73
90E	39.	6.00	---	24.50	620.49	$	1491.73
90E	41.	6.00	---	24.50	620.49	$	1491.73
CRED	9.	6.00	---	8.25	138.52	$	1048.22
CRED	29.	6.00	---	8.25	138.52	$	1048.22
GLO	15.	4.00	---	101.50	667.98	$	3530.00
90E	2.	4.00	---	9.00	190.85	$	962.76
90E	3.	4.00	---	9.00	190.85	$	962.76
90E	5.	4.00	---	9.00	190.85	$	962.76
PUMP	1.	4.00	---	2695.00	54086.40	$	40167.00

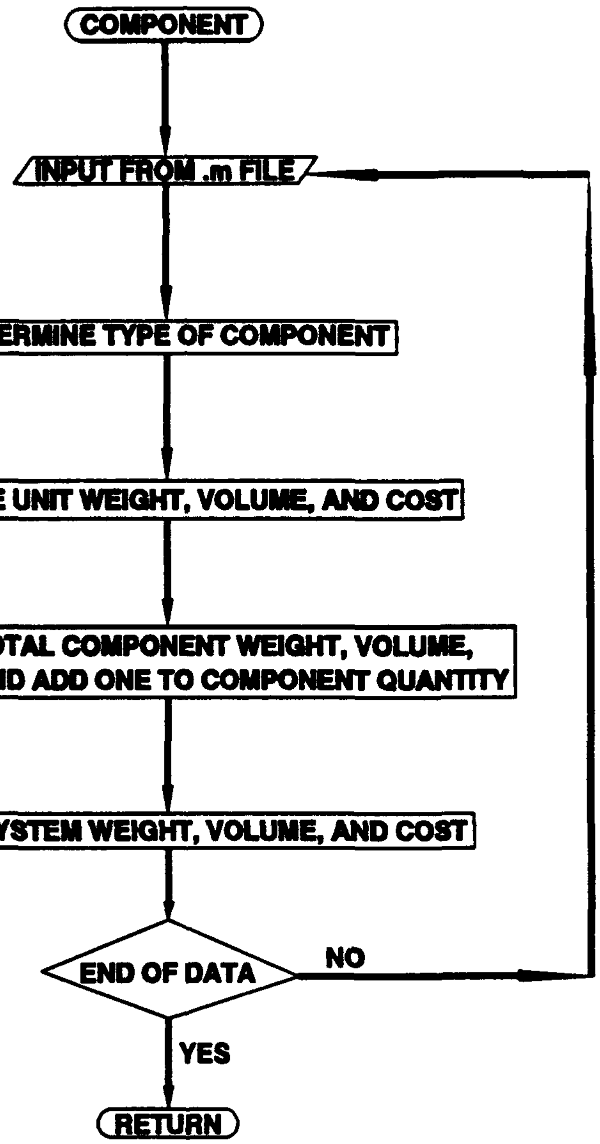
Table 6. (Continued).

```
TOTALS FOR COMPARTMENT BETWEEN BULKHEADS 2 AND 3
WITH MATERIAL DENSITY OF .283 LB/IN^3

TOTAL LENGTH OF 4 IN. PIPE IS    956.00 IN. WITH A TOTAL COST
OF $ 17303.60
TOTAL LENGTH OF 6 IN. PIPE IS   1335.23 IN. WITH A TOTAL COST
OF $ 50805.50

TOTAL NO. OF 4 IN. ELBOWS   5 WITH A TOTAL COST OF $  4813.80
TOTAL NO. OF 6 IN. ELBOWS   5 WITH A TOTAL COST OF $  7458.65
TOTAL NO. OF 6 IN. TEES   4 WITH A TOTAL COST OF $ 12353.16
TOTAL NO. OF 6X4 REDUCERS   4 WITH A TOTAL COST OF $  4192.88
TOTAL NO. OF 4 IN. VALVES   1 WITH A TOTAL COST OF $  3530.00
TOTAL NO. OF 6 IN. VALVES   1 WITH A TOTAL COST OF $  3530.00
TOTAL NO. OF PUMPS   1 WITH A TOTAL COST OF $ 40167.00

TOTAL WEIGHT OF THIS SECTION IS   8198.13 LBS.
TOTAL VOLUME OF THIS SECTION IS 123892.80 IN^3
TOTAL COST OF THIS SECTION IS $144154.50
```

APPENDIX A
FLOWCHART FOR BENEFIT ANALYSIS PROGRAM


BENEFIT
INPUT FILENAME, MATERIAL DENSITY, COMPARTMENT ID
INPUT FROM .h FILE
PIPE
NO
END OF DATA
NO
YES
YES
A
RECORD VALUES FOR X, Y, AND Z LOCATIONS AND OCCURRENCE NO.
END OF DATA
NO
YES
FIND PIPE VALUES WITH SAME OCCURRENCE NUMBERS
COMPUTE X, Y, AND Z LENGTHS
COMPUTE PIPE LENGTHS
DENSVOL
OUTPUT LENGTH, WEIGHT, VOLUME, COST
MORE PIPE VALUES
YES
NO
A
COMPONENT
OUTPUT COMPONENT QUANTITY, WEIGHT, VOLUME, COST
OUTPUT SYSTEM WEIGHT, VOLUME, COST
END


DENSVOL
INPUT FROM .m FILE
OCCURRENCE NUMBERS EQUAL
NO
YES
READ VALUES FOR INSIDE AND OUTSIDE DIAMETERS AND UNIT COST
ADD TO TOTAL PIPE LENGTH AND TOTAL COST FOR PIPE SIZE
COMPUTE UNIT WEIGHT AND UNIT VOLUME OF PIPE
ADD TO SYSTEM WEIGHT, VOLUME, AND COST
REWIND .m FILE
RETURN


COMPONENT
INPUT FROM .m FILE
DETERMINE TYPE OF COMPONENT
COMPUTE UNIT WEIGHT, VOLUME, AND COST
ADD TO TOTAL COMPONENT WEIGHT, VOLUME, AND COST AND ADD ONE TO COMPONENT QUANTITY
ADD TO SYSTEM WEIGHT, VOLUME, AND COST
END OF DATA
NO
YES
RETURN

APPENDIX B
LISTING OF BENEFIT ANALYSIS PROGRAM

```
      PROGRAM BENEFIT
COMMENT -- BENEFIT ANALYSIS PROGRAM, ADVANCED AUXILIARY SYSTEMS
COMMENT -- DESIGN PROCESS
COMMENT -- WRITTEN BY THE NAVAL SURFACE WARFARE CENTER, CARDEROCK
COMMENT -- DIVISION, CODE 824, ANNAPOLIS, MD
COMMENT -- THIS PRCGRAM IS TO BE USED WITH OUTPUT FILES FROM
COMMENT -- INTERGRAPH CORP. ENGINEERING MODELING SYSTEM AND AUXILIARIES
COMMENT -- ROUTING PROGRAM (I/EMS, I/ROUTE VERSION 1.4.5) TO CALCULATE
COMMENT -- AUXILIARY SYSTEM CHARACTERISTICS
COMMENT -- ALL DIMENSIONS BASED ON SCHEDULE 40 PIPE AND FITTINGS
COMMENT -- PROGRAM CURRENTLY WRITTEN FOR 2 IN., 4 IN. AND 6 IN. NPS
COMMENT -- PIPE.  ALL UNIT COSTS INCLUDE MATERIAL AND LABOR
      REAL AX(99),AY(99),AZ(99),AANPS1(99),AANPS2(99)
      REAL ZOCC,YOCC(99),YYOCC,XOCC1(99),ZOCC1,ZOCC2
      CHARACTER*64 HNAME,MNAME,PIECE,MTYPE,BLOCK,INTNAME
      CHARACTER*64 COMPN,NAME,BE1,BE2,SCH1,SCH2,L1,BLANK1
      CHARACTER*64 KNAME(99),KSCH1(99),SECID
COMMENT -- INITIALIZE VARIABLES
      DATA TOTWT /0.00/, TOTVOL /0.00/, TOTCOST /0.00/
      DATA PLEN2 /0.00/, PLEN4 /0.00/, PLEN6 /0.00/, NUMEL2 /0/
      DATA NUMEL4 /0/, NUMEL6 /0/, NUMT2 /0/, NUMT4 /0/, NUMT6 /0/
      DATA NUMR2 /0/, NUMR4 /0/, NUMR6 /0/, NUMV2 /0/, NUMV4 /0/
      DATA NUMV6 /0/, NUMPMP /0/, COSTP2 /0.00/, COSTP4 /0.00/
      DATA COSTP6 /0.00/, CEL2 /0.00/, CEL4 /0.00/, CEL6 /0.00/
      DATA CT2 /0.00/, CT4 /0.00/, CT6 /0.00/, CR2 /0.00/
      DATA CR4 /0.00/, CR6 /0.00/, CV2 /0.00/, CV4 /0.00/
      DATA CV6 /0.00/, CPM /0.00/
COMMENT -- INPUT FROM I/ROUTE OUTPUT FILE WITH .h EXTENSION, THIS
COMMENT -- FILE MUST BE MODIFIED BEFORE USE
      WRITE (*,10)
10    FORMAT ('  INPUT .h FILENAME [WITH EXTENSION] ')
      READ (*,11) HNAME
COMMENT -- INPUT FROM I/ROUTE OUTPUT FILE WITH .m EXTENSION, THIS
COMMENT -- FILE MUST BE MODIFIED BEFORE USE
      WRITE (*,12)
11    FORMAT (A)
12    FORMAT ('  INPUT .m FILENAME [WITH EXTENSION] ')
      READ (*,11) MNAME
      OPEN (1,FILE=HNAME)
      OPEN (2,FILE=MNAME)
      WRITE (*,40)
40    FORMAT ('  INPUT COMPARTMENT IDENTIFICATION ')
      READ (*,11) SECID
      WRITE (*,43)
43    FORMAT ('  INPUT DENSITY OF PIPING MATERIAL [lb/in^3] ')
      READ (*,44) DENSITY
44    FORMAT (F5.3)
```

```
      WRITE (*,19)
19    FORMAT (2X)
      WRITE (*,16)
16    FORMAT (2X,' COMP ',' OCC ','     NPS   ',' LENGTH ',
     C' WEIGHT  ',' VOLUME  ','     COST ')
      WRITE (*,18)
18    FORMAT (2X,'----------------------------------------------------------
     C------')
      IA=1
100   READ (1,13,END=200) PIECE,ZOCC,ICP,X,Y,Z,NODE,IDIR,
     CISECT,IFLAGS,ITOPO,ISEQ,IBRANCH,ISG,LAST
13    FORMAT (BN,A8,F5.0,I4,3F13.2,9I7)
      IF (PIECE .NE. ' PIPE   ') GOTO 100
      YOCC(IA)=ZOCC
      AX(IA)=X
      AY(IA)=Y
      AZ(IA)=Z
      IA=IA+1
      GOTO 100
200   IB=1
201   IC=IB+1
COMMENT -- CHECK THAT OCCURRENCE NUMBERS ARE THE SAME
      IF (YOCC(IB) .EQ. YOCC(IC)) THEN
        YYOCC=YOCC(IB)
        XLEN=AX(IB)-AX(IC)
        YLEN=AY(IB)-AY(IC)
        ZLEN=AZ(IB)-AZ(IC)
        PIPELEN=SQRT((XLEN**2)+(YLEN**2)+(ZLEN**2))
        CALL DENSVOL (YYOCC,PIPELEN,TOTWT,TOTVOL,TOTCOST,PLEN2,
     CPLEN4,PLEN6,DENSITY,COSTP2,COSTP4,COSTP6)
      ENDIF
      IB=IC+1
      IF (IB .LT. IA) GOTO 201
      CALL COMPONENT (NUMEL2,NUMEL4,NUMEL6,NUMT2,NUMT4,NUMT6,
     CNUMR4,NUMR6,NUMV2,NUMV4,NUMV6,NUMPMP,TOTWT,TOTVOL,DENSITY,
     CTOTCOST,CEL2,CEL4,CEL6,CT2,CT4,CT6,CR2,CR4,CR6,CV2,CV4,CV6,CPM)
      WRITE (*,19)
      WRITE (*,42) SECID
42    FORMAT (2X,' TOTALS FOR COMPARTMENT ',A50)
      WRITE (*,45) DENSITY
45    FORMAT (2X,' WITH MATERIAL DENSITY OF',F5.3,' LB/IN^3 ')
      WRITE (*,27)
      IF (PLEN2 .NE. 0.00) WRITE (*,22) PLEN2,COSTP2
      IF (PLEN4 .NE. 0.00) WRITE (*,23) PLEN4,COSTP4
      IF (PLEN6 .NE. 0.00) WRITE (*,24) PLEN6,COSTP6
22    FORMAT (2X,' TOTAL LENGTH OF 2 IN. PIPE IS ',F9.2,' IN.',
     C' WITH A TOTAL COST OF $',F9.2)
```

```
23    FORMAT (2X,' TOTAL LENGTH OF 4 IN. PIPE IS ',F9.2,' IN.',
     C' WITH A TOTAL COST OF $',F9.2)
24    FORMAT (2X,' TOTAL LENGTH OF 6 IN. PIPE IS ',F9.2,' IN.',
     C' WITH A TOTAL COST OF $',F9.2)
      WRITE (*,27)
27    FORMAT (2X)
      IF (NUMEL2 .NE. 0) WRITE (*,28) NUMEL2,CEL2
28    FORMAT (2X,' TOTAL NO. OF 2 IN. ELBOWS',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMEL4 .NE. 0) WRITE (*,29) NUMEL4,CEL4
29    FORMAT (2X,' TOTAL NO. OF 4 IN. ELBOWS',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMEL6 .NE. 0) WRITE (*,30) NUMEL6,CEL6
30    FORMAT (2X,' TOTAL NO. OF 6 IN. ELBOWS',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMT2 .NE. 0) WRITE (*,31) NUMT2,CT2
31    FORMAT (2X,' TOTAL NO. OF 2 IN. TEES',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMT4 .NE. 0) WRITE (*,32) NUMT4,CT4
32    FORMAT (2X,' TOTAL NO. OF 4 IN. TEES',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMT6 .NE. 0) WRITE (*,33) NUMT6,CT6
33    FORMAT (2X,' TOTAL NO. OF 6 IN. TEES',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMR4 .NE. 0) WRITE (*,34) NUMR4,CR4
34    FORMAT (2X,' TOTAL NO. OF 4X2 REDUCERS',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMR6 .NE. 0) WRITE (*,35) NUMR6,CR6
35    FORMAT (2X,' TOTAL NO. OF 6X4 REDUCERS',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMV2 .NE. 0) WRITE (*,36) NUMV2,CV2
36    FORMAT (2X,' TOTAL NO. OF 2 IN. VALVES',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMV4 .NE. 0) WRITE (*,37) NUMV4,CV4
37    FORMAT (2X,' TOTAL NO. OF 4 IN. VALVES',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMV6 .NE. 0) WRITE (*,38) NUMV6,CV6
38    FORMAT (2X,' TOTAL NO. OF 6 IN. VALVES',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      IF (NUMPMP .NE. 0) WRITE (*,39) NUMPMP,CPM
39    FORMAT (2X,' TOTAL NO. OF PUMPS',I4,
     C' WITH A TOTAL COST OF $',F9.2)
      WRITE (*,19)
      WRITE (*,20) TOTWT
20    FORMAT (2X,' TOTAL WEIGHT OF THIS SECTION IS ',F9.2,' LBS.')
      WRITE (*,21) TOTVOL
```

```
21     FORMAT (2X,' TOTAL VOLUME OF THIS SECTION IS ',F9.2,' IN^3')
       WRITE (*,46) TOTCOST
46     FORMAT (2X,' TOTAL COST OF THIS SECTION IS $',F9.2)
       END
       SUBROUTINE DENSVOL (YYOCC,PIPELEN,TOTWT,TOTVOL,TOTCOST,PLEN2,
      CPLEN4,PLEN6,DENSITY,COSTP2,COSTP4,COSTP6)
       CHARACTER*64 MTYPE,BLOCK,INTNAME
       CHARACTER*64 COMPN,NAME,BE1,BE2,SCH1,SCH2,L1,BLANK1
       PI=3.14159
       UNITCST=0.00
300    READ (2,14,END=410) MTYPE,BLOCK,ZOCC1,BLANK1,ZOCC2,
      CINTNAME,COMPN,NAME,ANPS1,ANPS2,BE1,BE2,SCH1,SCH2,L3,
      CL2,L1,ALO
14     FORMAT (BN,A8,A12,F4.0,A7,F4.0,A22,A7,A6,2F8.2,4A6,2I6,A9,F6.2)
       IF (ZOCC1 .NE. YYOCC) GOTO 300
COMMENT -- 2 IN. NPS PIPE
       IF (ANPS1 .EQ. 2.00) THEN
         DO=2.375
         DI=2.067
         PLEN2=PLEN2+PIPELEN
         UNITCST=7.93*PIPELEN
         COSTP2=COSTP2+UNITCST
         GOTO 400
       ENDIF
COMMENT -- 4 IN. NPS PIPE
       IF (ANPS1 .EQ. 4.00) THEN
         DO=4.500
         DI=4.026
         PLEN4=PLEN4+PIPELEN
         UNITCST=18.10*PIPELEN
         COSTP4=COSTP4+UNITCST
         GOTO 400
       ENDIF
COMMENT -- 6 IN. NPS PIPE
       IF (ANPS1 .EQ. 6.00) THEN
         DO=6.625
         DI=6.065
         PLEN6=PLEN6+PIPELEN
         UNITCST=38.05*PIPELEN
         COSTP6=COSTP6+UNITCST
         GOTO 400
       ENDIF
410    WRITE (*,17)
17     FORMAT ('  DID NOT READ ANYTHING FROM .m FILE ')
400    UNITWT=(PI/4)*((DO*DO-DI*DI)*DENSITY+.037*DI*DI)
       UNITVOL=(PI/4)*DO*DO
       WEIGHT=PIPELEN*UNITWT
```

```
      VOLUME=PIPELEN*UNITVOL
      TOTWT=WEIGHT+TOTWT
      TOTVOL=VOLUME+TOTVOL
      TOTCOST=TOTCOST+UNITCST
      WRITE (*,15) ZOCC1,ANPS1,PIPELEN,WEIGHT,VOLUME,UNITCST
15    FORMAT (2X,' PIPE ',F5.0,4F9.2,'  $',F9.2)
      REWIND 2
      RETURN
      END
      SUBROUTINE COMPONENT (NUMEL2,NUMEL4,NUMEL6,NUMT2,NUMT4,NUMT6,
     CNUMR4,NUMR6,NUMV2,NUMV4,NUMV6,NUMPMP,TOTWT,TOTVOL,DENSITY,
     CTOTCOST,CEL2,CEL4,CEL6,CT2,CT4,CT6,CR2,CR4,CR6,CV2,CV4,CV6,CPM)
      CHARACTER*64 MTYPE,BLOCK,INTNAME
      CHARACTER*64 COMPN,NAME,BE1,BE2,SCH1,SCH2,L1,BLANK1
502   READ (2,25,END=510) MTYPE,BLOCK,ZOCC1,BLANK1,ZOCC2,
     CINTNAME,COMPN,NAME,ANPS1,ANPS2,BE1,BE2,SCH1,SCH2,L3,
     CL2,L1,AL0
25    FORMAT (BN,A8,A12,F4.0,A7,F4.0,A22,A7,A6,2F8.2,4A6,2I6,A9,F6.2)
      UNITCOST=0.00
      IF (NAME .EQ. '90E   ') THEN
COMMENT -- 2 IN. NPS LR ELBOW
        IF (ANPS1 .EQ. 2.00) THEN
        WT=1.60*(DENSITY/.283)
        VOL=26.58
        NUMEL2=NUMEL2+1
        TOTWT=TOTWT+WT
        TOTVOL=TOTVOL+VOL
        UNITCOST=269.69
        CEL2=CEL2+UNITCOST
        ENDIF
COMMENT -- 4 IN. NPS LR ELBOW
        IF (ANPS1 .EQ. 4.00) THEN
        WT=9.00*(DENSITY/.283)
        VOL=190.85
        NUMEL4=NUMEL4+1
        TOTWT=TOTWT+WT
        TOTVOL=TOTVOL+VOL
        UNITCOST=962.76
        CEL4=CEL4+UNITCOST
        ENDIF
COMMENT -- 6 IN. NPS LR ELBOW
        IF (ANPS1 .EQ. 6.00) THEN
        WT=24.5*(DENSITY/.283)
        VOL=620.49
        NUMEL6=NUMEL6+1
        TOTWT=TOTWT+WT
        TOTVOL=TOTVOL+VOL
```

```
        UNITCOST=1491.73
        CEL6=CEL6+UNITCOST
        ENDIF
      GOTO 511
      ENDIF
      IF (NAME .EQ. 'TEE   ') THEN
COMMENT -- 2 IN. NPS STRAIGHT TEE
        IF (ANPS1 .EQ. 2.00) THEN
        WT=3.50*(DENSITY/.283)
        VOL=27.965
        NUMT2=NUMT2+1
        TOTWT=TOTWT+WT
        TOTVOL=TOTVOL+VOL
        UNITCOST=1261.14
        CT2=CT2+UNITCOST
        ENDIF
COMMENT -- 4 IN. NPS STRAIGHT TEE
        IF (ANPS1 .EQ. 4.00) THEN
        WT=12.00*(DENSITY/.283)
        VOL=161.031
        NUMT4=NUMT4+1
        TOTWT=TOTWT+WT
        TOTVOL=TOTVOL+VOL
        UNITCOST=1742.65
        CT4=CT4+UNITCOST
        ENDIF
COMMENT -- 6 IN. NPS STRAIGHT TEE
        IF (ANPS1 .EQ. 6.00) THEN
        WT=34.00*(DENSITY/.283)
        VOL=467.539
        NUMT6=NUMT6+1
        TOTWT=TOTWT+WT
        TOTVOL=TOTVOL+VOL
        UNITCOST=3088.29
        CT6=CT6+UNITCOST
        ENDIF
      GOTO 511
      ENDIF
      IF (NAME .EQ. 'CRED  ') THEN
COMMENT -- 4X2 IN. NPS CONCENTRIC REDUCER
        IF (ANPS1 .EQ. 4.00 .AND. ANPS2 .EQ. 2.00) THEN
        WT=3.00*(DENSITY/.283)
        VOL=40.66
        NUMR4=NUMR4+1
        TOTWT=TOTWT+WT
        TOTVOL=TOTVOL+VOL
        UNITCOST=953.47
```

```
         CR4=CR4+UNITCOST
         ENDIF
COMMENT -- 6X4 IN. NPS CONCENTRIC REDUCER
         IF (ANPS1 .EQ. 6.00 .AND. ANPS2 .EQ. 4.00) THEN
         WT=8.25*(DENSITY/.283)
         VOL=138.52
         NUMR6=NUMR6+1
         TOTWT=TOTWT+WT
         TOTVOL=TOTVOL+VOL
         UNITCOST=1048.22
         CR6=CR6+UNITCOST
         ENDIF
      GOTO 511
      ENDIF
      IF (NAME .EQ. 'GLO   ') THEN
COMMENT -- 2 IN. NPS GLOBE VALVE
         IF (ANPS1 .EQ. 2.00) THEN
         WT=33.80*(DENSITY/.283)
         VOL=183.78
         NUMV2=NUMV2+1
         TOTWT=TOTWT+WT
         TOTVOL=TOTVOL+VOL
         UNITCOST=3530.00
         CV2=CV2+UNITCOST
         ENDIF
COMMENT -- 4 IN. NPS GLOBE VALVE
         IF (ANPS1 .EQ. 4.00) THEN
         WT=101.5*(DENSITY/.283)
         VOL=667.98
         NUMV4=NUMV4+1
         TOTWT=TOTWT+WT
         TOTVOL=TOTVOL+VOL
         UNITCOST=3530.00
         CV4=CV4+UNITCOST
         ENDIF
COMMENT -- 6 IN. NPS GLOBE VALVE
         IF (ANPS1 .EQ. 6.00) THEN
         WT=219.8*(DENSITY/.283)
         VOL=1425.50
         NUMV6=NUMV6+1
         TOTWT=TOTWT+WT
         TOTVOL=TOTVOL+VOL
         UNITCOST=3530.00
         CV6=CV6+UNITCOST
         ENDIF
      GOTO 511
      ENDIF
```

```
COMMENT -- PUMP
      IF (NAME .EQ. 'CAP   ') THEN
      WT=2695.00
      VOL=54086.40
      NUMPMP=NUMPMP+1
      TOTWT=TOTWT+WT
      TOTVOL=TOTVOL+VOL
      UNITCOST=40167.00
      CPM=CPM+UNITCOST
      NAME='PUMP  '
      GOTO 511
      ENDIF
      GOTO 502
510   RETURN
511   WRITE (*,26) NAME,ZOCC1,ANPS1,WT,VOL,UNITCOST
26    FORMAT (3X,A6,F4.0,F9.2,5X,'---',2X,F8.2,F9.2,'  $',F9.2)
      TOTCOST=TOTCOST+UNITCOST
      GOTO 502
      END
```

APPENDIX C
PROCEDURE FOR THE AUTOMATED DESIGN PROCESS

The following procedure is for developing a parametric ship and auxiliary system model in the Ship Parametric Modeling Program and determining the system characteristics (i.e., weight, volume, and cost) in the Benefit Analysis Program. It is assumed that the reader has a working knowledge of I/EMS (Version 1.4.5.02)[3] and I/ROUTE (Version 1.4.5.29).[4] Note that the default length units for I/EMS are inches.

To create the parametric ship model:

1) Turn on base coordinate system.

2) Create associative expressions for the x, y, and z coordinates of the points that will define the locations for decks and bulkheads in terms of ship's length, width, and height.

3) Toggle shared parameters on.

4) Place associative point on coordinate system for point on first bulkhead using the x, y, and z associative expressions created above.

5) Place a view aligned coordinate system on this first point.

6) Place all other associative points that define this bulkhead and the decks in this bulkhead compartment relative to the just placed view aligned coordinate system and using the x, y, and z associative expressions created.

7) Place associative line segments between the corresponding associative points.

8) Repeat steps 4 through 7 for the rest of the ship's bulkheads.

9) Place associative line segments between consecutive bulkheads to represent decks.

To create the parametric auxiliary system model:

10) Create associative expressions for the x, y, and z locations of the ends of all pipe and the center of all components.

11) Within first bulkhead-to-bulkhead compartment, place associative points relative to the view aligned coordinate system on the forward bulkhead of this

compartment. Use the associative expressions created in step 10 to place the points.

12) Place a view aligned coordinate system on each of the associative points just placed.

13) Route the piping system though each of the associative points placed by tentative keypoint snap on each point. The line sequence number should be changed for each bulkhead compartment.

14) Attach the construction planes of each pipe/component to the view aligned coordinate system defining the location of that pipe/component. Note: only need to attach the construction planes on one end of a pipe segment -- if both ends are attached, the pipe may be overconstrained and lead to errors.

15) Repeat steps 11 through 14 for all bulkhead compartments.

16) A pump model can be created in an external reference file and then attached to an associative point in the piping system model. However, the pump will not be recognized as being part of the piping system by I/ROUTE. Therefore, also place an unused piping component at this associative point (e.g., I used a piping cap in the zonal fire main model).

Creating the Ship Parametric Modeling Program output:

17) Run Extract Isometrics for the line sequence number of the first bulkhead section.

18) Run Stress Analysis Input for the line sequence number of the first bulkhead section.

19) Repeat steps 17 and 18 for each of the remaining bulkhead sections.

Calculating the system characteristics with the Benefit Analysis Program:

20) Make the necessary modifications to the .h file. First, delete all sections other than the "Design file data sorted by topo." Then, delete the first part of this section that lists just the component information.

21) Modify the .m fiie by replacing the double apostrophe marks (") with either a zero or a space.

22) Run the Benefit Analysis Program for each bulkhead compartment using the modified .h and .m files as the input.

The Benefit Analysis Program will prompt the user for a compartment identification and the density of the piping material. The compartment identification should not exceed 50 characters and the density is in lbm/in^3. Modifications can now be made to the parametric ship and auxiliary system model by editing the associative expressions in the Ship Parametric Modeling Program, and new system characteristics can then be obtained by repeating steps 17 through 22.

REFERENCES

1. Shiffler, Mark E., "Distributed Fire Main System Concept Development and Preliminary Analysis," DTRC-TM-27-91-68 (Dec 1991).

2. Nordham, David J., "Automated Ship Auxiliary Systems Design Process -- Ship Parametric Modeling Program," CARDEROCKDIV-PAS-92/40 (Mar 1993).

3. "Intergraph/Engineering Modeling System (I/EMS) Reference Manual," Intergraph Corporation, DMA103770 (15 Oct 1990).

4. "Intergraph/Vehicle Routing Design System (I/ROUTE) Reference Manual," Intergraph Corporation, DMA000510 (15 Jun 1991).

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